The Dynamics of Cobbles in and Near the Surf Zone

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LONG-TERM GOAL

The long-range goals of this research are to develop, using laboratory experiments, theoretical analyses and field observations, a basic understanding and, eventually, a predictive capability of the behavior of large bottom particles (cobbles/mines) in the shoaling, wave-breaking and swash zones. Here, the size classification of cobbles used by the American Geophysical Union as particles in the diameter range 6.4 to 25.6 cm is employed. Disk-shaped anti-tank mines are of comparable size.

SCIENTIFIC OBJECTIVES

The scientific objectives of this research are directed toward better understanding the motion and burial/scouring of cobbles on beaches, which are permeable with movable sand bedforms. These objectives will permit a better understanding of (i) the long-time dynamics of sand ripples formed in a model surf zone, and (ii) the process of burial/scouring of cobbles on a sandy beach with ripples in periodic and spatially dependent flow. In particular, we wish to study (i) the evolution of an initially flat sandy beach; (ii) the long-time behavior of the bottom topography, and (iii) the time evolution of model cobbles.

APPROACH

Carefully designed laboratory experiments are key to achieving the stated scientific goals. The experiments are conducted using a large (32 x 1.8 x 0.9 m) wave tank located at Arizona State University. The tank is equipped with a computer-controlled wave maker and a sloping beach. The background flow characteristics are measured using Acoustic Doppler velocimetry (ADV), particle image velocimetry (PIV), wave gauges, traversing platforms, data acquisition systems, and other standard methods. The change in bottom topography and cobble behavior was monitored by employing video cameras and the resulting data were analyzed using in-house developed software.

WORK COMPLETED

This work is a continuation of our previous studies (Lucccio et al, 1998: Voropayev et al., 1998; 1999; 2000a) where, as a first step, a solid impermeable beach with artificial roughness was used. In the present study a homogeneous layer of sand was placed on the slope, which significantly complicated the problem. To achieve the scientific goals formulated above, two series of experiments were conducted in a large wave tank. In the first, a layer of sand was placed along the sloping bottom of the tank. The evolution of an initially flat sandy bed as well as the processes of ripple formation and their dynamics in time and space-dependent surf-zone flow were studied. In the second series, model mines and cobbles of different size and density were placed along the sandy slope and their evolution with time was investigated. Quantitative data on the background flow characteristics, the behavior of cobbles and changes of bottom topography were obtained using high-resolution video cameras, a three-component acoustic Doppler velocimeter, a high resolution PIV system (for particle tracking) and other standard techniques. Physical explanations of the results obtained were also advanced.

RESULTS

Our research for the FY 00 was concentrated mostly on (i) bottom topography transformation and (ii) cobble behavior on the slope under conditions similar to those occurring in a shoaling surf zone with a sandy bed.

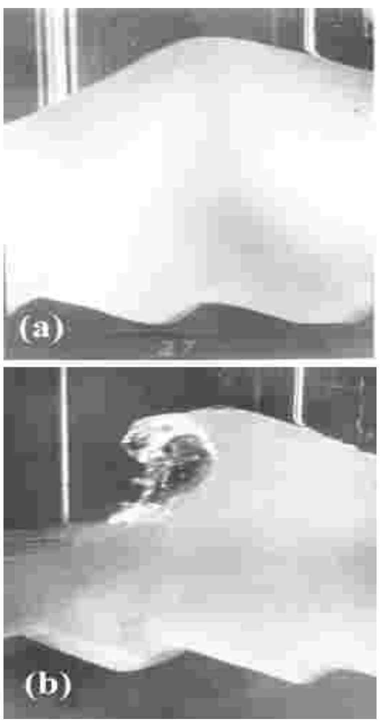

Figure 1. Typical nonlinear wave propagating (a) from right to left along sandy slop and then breaking (b) near the break point. Sand ripples are clearly seen at the bottom.

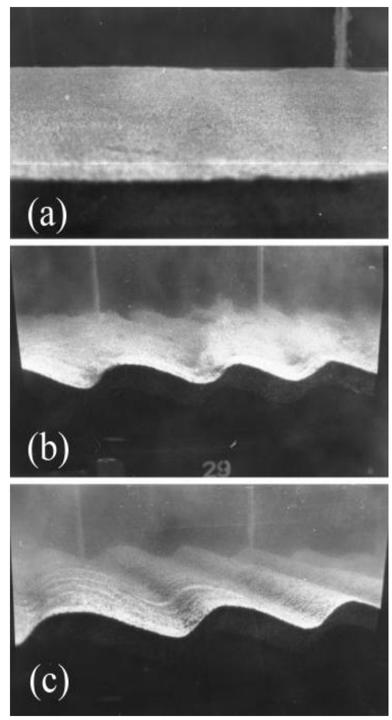

Figure 2. Photographs showing (a) initially flat sandy bottom; (b) growing and (c) quasi-steady sand ripples formed on a slope in steady waves with relatively large intensity.

A typical nonlinear wave propagating (Fig. 1a) from right to left along sandy slope and then breaking (Fig. 1b) near the break point is shown in Fig. 1. To control the fluid motion induced by these waves, the wave height and the horizontal and vertical components of velocity were measured at different positions along the slope using a wave-guide and three-component acoustic ADV velocimeter. The principal outcomes to date are as follows. The initially flat bottom rapidly changes its topography and after some transitional time it reaches quasi-steady state with a system of sand ripples (Fig. 2) and a large bar, which is formed latter to the left of the break point. While the incoming wave characteristics are fixed, the bottom topography never precisely reaches a steady state. The bottom slowly changes mostly because of ripple drift along the slope and because of the transformation of the bar. When wave characteristics are changed the bottom topography adjusts accordingly. A new quasi-steady state is reached after some adjustment time interval. The experiments also demonstrate that, at large times, the system of ripples is not stable but migrates with some drift velocity. Two kinds of instability were observed. The first is related to the periodic merging and splitting of ripples. This effect was observed and explained for a horizontal bottom under spatially homogeneous oscillatory flow in Voropayev et al. (1999). The process resembles the periodic appearance of dislocations in an initially regular ripple pattern. These dislocations induce the migration of the nearest ripples. With time, the new or merged ripple spreads laterally across the flow. Because the typical spacing between ripples decreases or increases during the ripple merging or splitting, the whole system of ripples drifts with some typical velocity U_d' that has no preferable direction and averaged over a large time interval is approximately equal to zero. It is shown that, in addition to the mentioned instability, another kind of instability is possible under progressive waves along the slope. This instability is related to a steady ripple drift with unidirectional (at fixed distance) ripple drift velocity U''_d along the slope which is comparable in magnitude with U'_d. The data on the ripple growth, transition time intervals, quasi-steady ripple characteristics and net drift velocity at different distances along the slope and different wave parameters were collected and compared with the proposed estimates.

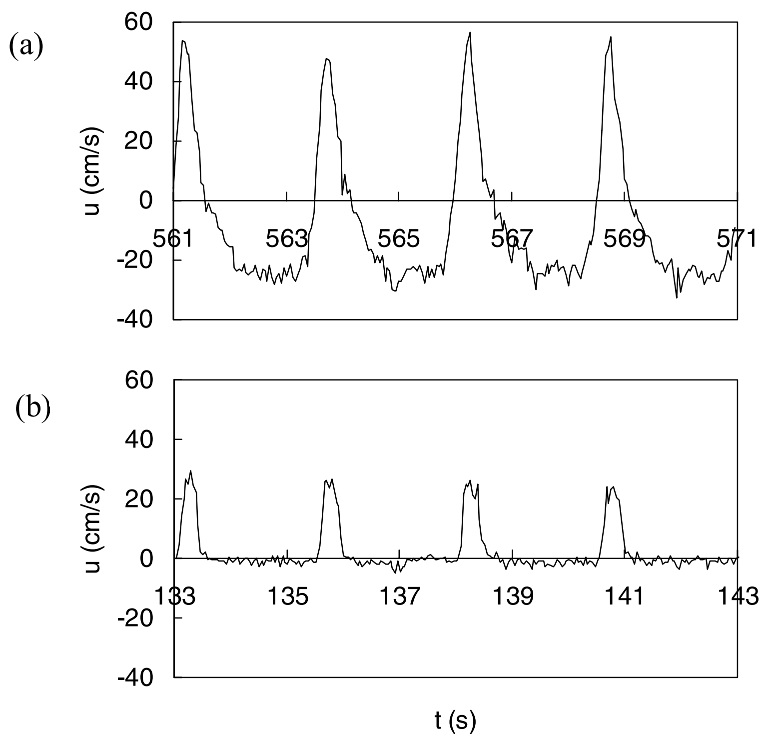

Figure 3. Typical examples of the real-time horizontal along-slope velocity records as obtained (a) approximately 5 cm above the ripple trough at the level of ripple crest and (b) in the boundary layer approximately 0.1 cm above the ripple crest.

Using the three-component ADV and high resolution PIV system, an attempt was made to obtain information on the details of flow around movable sand ripples. Such data were obtained recently by Ridler and Sleath (2000) but only for fixed solid rippled profiles. In contrast to solid artificial ripples, the sand ripples can move under the waves and besides the two nearest ripples are usually different from each other. This significantly complicates the measurements and interpretation of the velocity field. Figure 3 gives typical real-time horizontal along-slope velocity records. Data on Fig. 3a were taken above the ripple trough at the level of ripple crest and data on Fig. 3b were taken in the boundary layer approximately 0.1 cm above the ripple crest. The onshore velocity magnitude above the trough is approximately two times larger than in the boundary layer above the crest. Averaged over the wave period, the velocity above the trough is negative (offshore), while it is strongly positive just above the ripple crest. This means that, in the boundary layer above the crest, significant mean positive water drift is present and significant positive mean sediment transport may be expected here.

After the evolution of an initially flat sandy bed was reproduced in experiments, the model mines and cobbles of different size and density were placed along the sandy slope and their behavior with time was studied. Four different possibilities were reproduced in the experiments. (i) Steady cobble oscillations with zero mean displacement and with small scour. (ii) Mean onshore motion of relatively light cobbles. (iii) Periodic burial/unburial of relatively heavy cobbles (Fig. 4), of which the size is comparable to that of sand ripples. (iv) Burial/unburial of relatively large cobbles under the bar (Fig. 5) when the break point was changed (e.g. by changing wave characteristics or water depth). Experimental data on the behavior of cobbles, background flow characteristics and bottom topography were obtained using high-resolution video, ADV and high resolution DigImage velocimetry. Physical explanations for the results obtained were advanced. The next natural step in our studies is to quantify some of these processes and develop theoretical models. The main results obtained during the FY 00 are reported in Voropayev et al. (2000a,b).

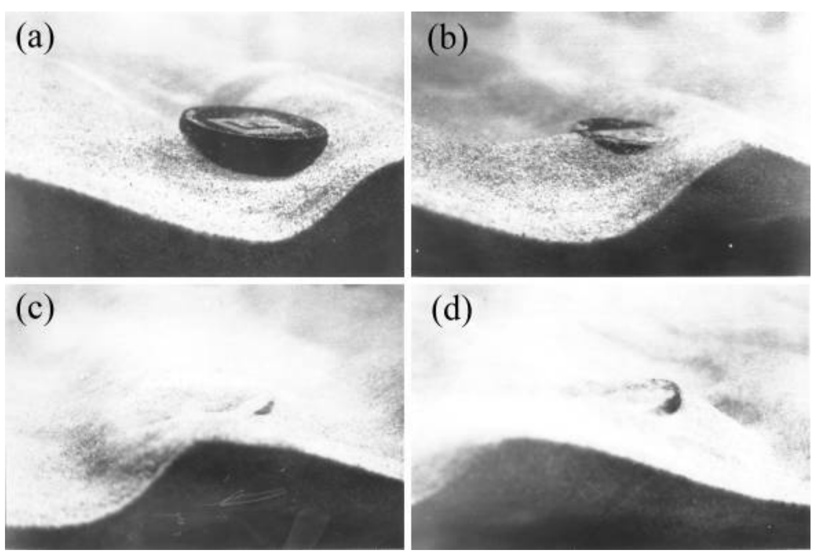

Figure 4. Photographs showing the burial of a relatively small cobble (diameter 9.1 cm) that was trapped between two adjacent ripples. As can be seen ripples slowly drift (from right to left). The trapped cobble (a) is first partly (b) and then completely buried (c). In (d) it starts to recover again. Time interval between frames (a) and (d) is approximately 6 min.

IMPACT/APPLICATION

The transport of large heavy "particles", such as cobbles, on a sandy sloping bottom submerged in a periodic spatially dependent flow, typical of a surf zone, is not well understood from a fundamental

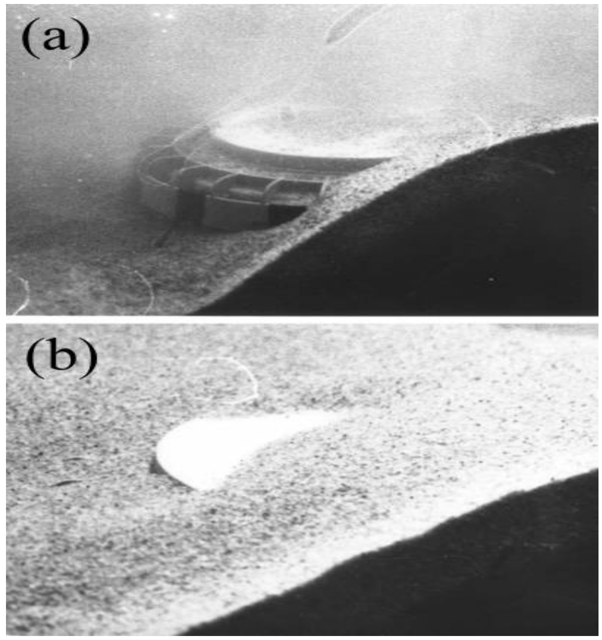

Figure 5. Photographs showing the burial of a relatively large cobble (model of mine, diameter 21 cm), which initially was above the sand bar when the incoming wave characteristics were changed. The cobble (a) slides to the trough at the onshore side of the bar and is slowly buried (b) under the drifting bar.

point of view. The present project is an integrated laboratory, theoretical and field program (carried out by NRL) that seeks to better understand this complex physical problem.

TRANSITIONS

Discussions between Dr. Todd Holland from the Naval Research Laboratory and project personnel at Arizona State University were held to develop a knowledge base that can be transitioned to the Navy.

RELATED PROJECTS

This project is linked to a field observational and modeling program that was carried out by personnel of the NRL at the Stennis Space Center under the direction of Dr. Todd Holland. Close collaboration between the laboratory and theoretical studies at Arizona State University and the mine-motion observation and modeling studies of NRL is continuing.

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PUBLICATIONS

Voropayev, S.I., Cense, A.W., McEachern, G.B., Boyer, D.L. and Fernando, H.J.S. 2000a. Dynamics of cobbles in the shoaling region of surf zone**.** *Ocean Engineering*, **28,** in press.

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